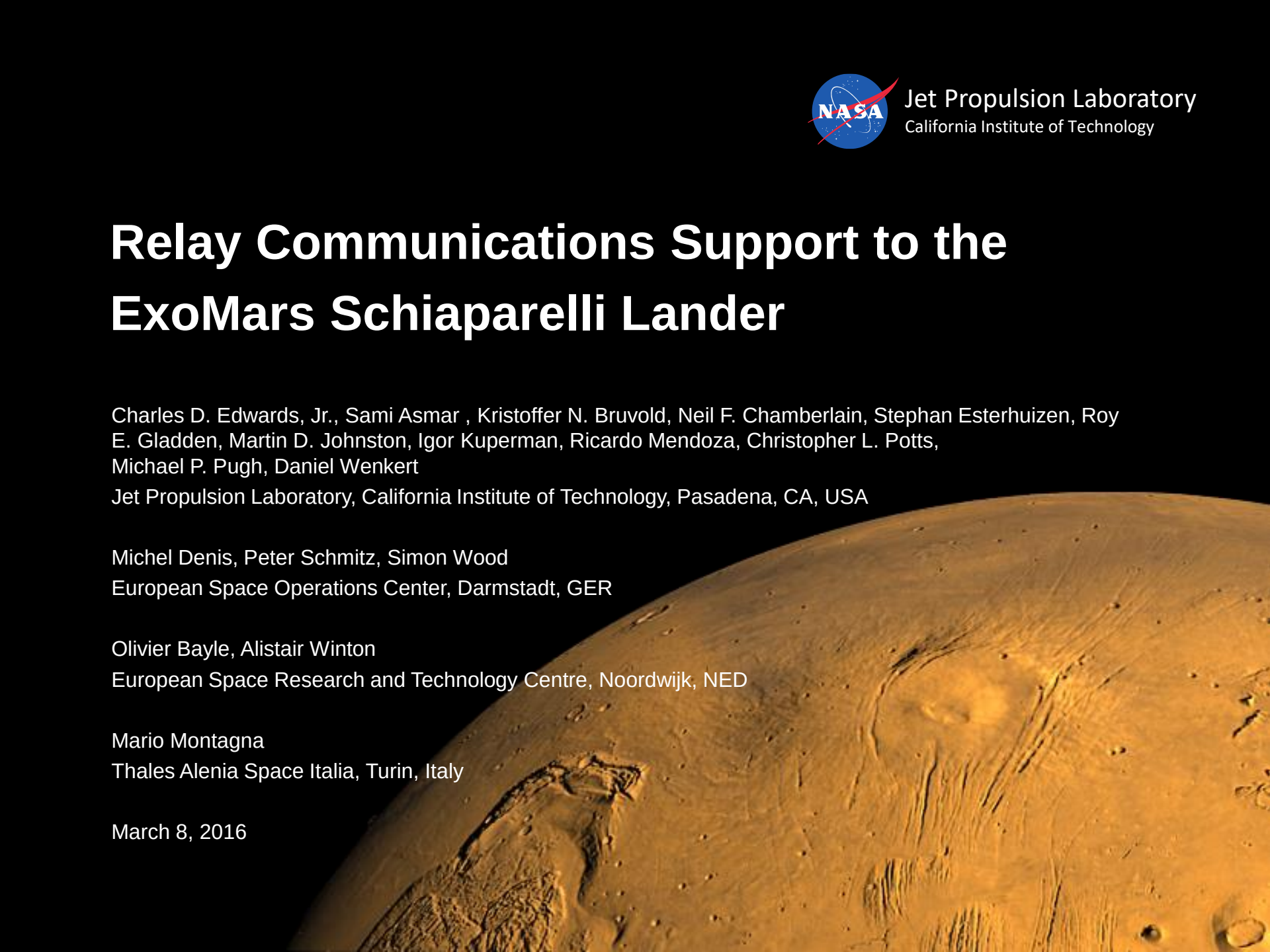

Jet Propulsion Laboratory
California Institute of Technology

Relay Communications Support to the ExoMars Schiaparelli Lander

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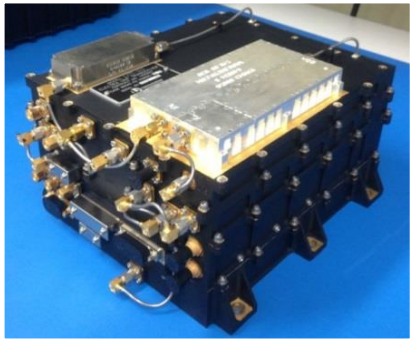
March 8, 2016

Outline

- ExoMars 2016 Mission
- Current Mars Relay Network Overview
- TGO & EDM Relay Systems
- Relay V&V Testing
- Critical Event Comm Support During EDM Separation and EDL
- EDM Surface Relay Support
- Summary

2016 ExoMars Mission Overview

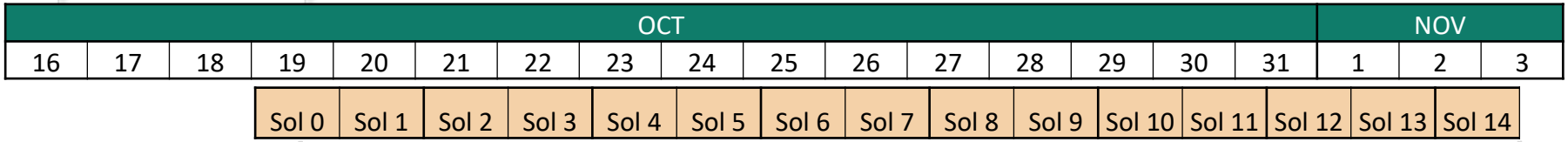
- ExoMars/Trace Gas Orbiter
  - Launched Mar 14, 2016 from Baikonur
  - MOI scheduled for Oct 19, 2016
  - Aerobrake in 2017 to 400 km circular orbit, 74 deg inclination
  - Science focus on detecting trace gases in Mars atmosphere
  - Carries NASA-provided redundant Electra UHF Transceivers
  - Planned operational lifetime through 2022
- Schiaparelli Lander, aka EDL Demonstrator Module (EDM)
  - Separation from TGO 3 d prior to Mars arrival
  - Ballistic trajectory to Meridiani Planum landing site
  - EDL critical event comm to TGO/Electra during its MOI via QinetiQ UHF transceiver
  - Battery-powered lander; 4-sol nominal lifetime
  - Primary focus is on demonstrating EDL technologies
  - Also carries DREAMS met package and DECA descent imager



EDM Mission Overview – Relay Services

EDM Separation
- 16-Oct 14:42 GMT (nominal)
- TGO/Electra open loop recording during SEP
- GMRT carrier detection

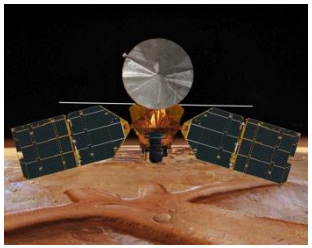
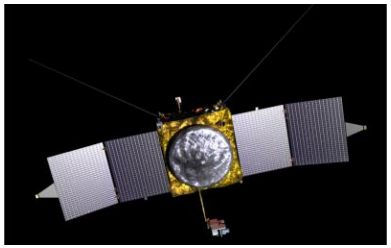
EDM EDL
- 19-Oct 14:47 GMT (nominal landing time)
- Occurs during TGO MOI (1305-1524 GMT)
- TGO/Electra open-loop recording
- MEX/Melacom open-loop recording
- GMRT carrier detection



EDM Surface Mission
- Up to 14 sols
- MRO, ODY, MAVEN relay services
- MEX relay services
- Possible GMRT signal detection

Operational Mars Relay Network – Oct 2016

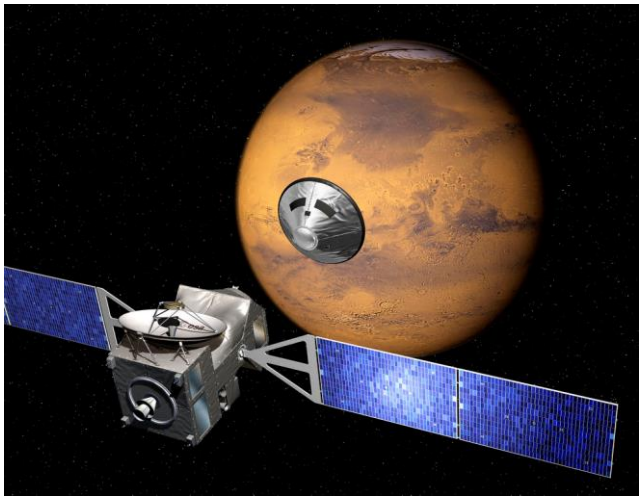


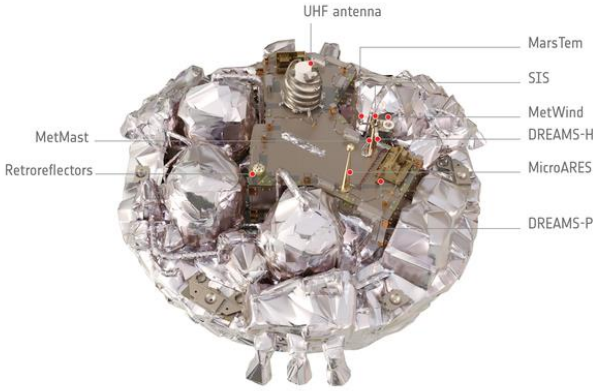



	Mars Odyssey	Mars Express	MRO	MAVEN
Agency:	NASA	ESA	NASA	NASA
Launch:	Apr 7, 2001	June 2, 2003	Aug 12, 2005	Nov 18, 2013
Orbit:	• 400 km circular • 93 deg inclination • Sun-synchronous	• 330 x 10,530 km elliptical • 86.9 deg inclination • Non sun-synchronous	• 255 x 320 km • 93 deg inclination • Sun-synchronous	• 150 x 6,200 km elliptical • 75 deg inclination • Non-sun-synchronous
Deep Space Link:				
- Band	• X-band	• X-band	• X-band	• X-band
- Power Amplifier	• 15 W SSPA	• 65 W TWTA	• 100 W TWTA	• 100 W TWTA
- High Gain Ant	• 1.3 m HGA	• 1.65 m HGA	• 3 m HGA	• 2 m HGA (body fixed)
Proximity Link:				
- Transceiver	• CE-505	• Melacom	• Electra	• Electra (single string)
- Protocol	• CCSDS Proximity-1	• CCSDS Proximity-1	• CCSDS Proximity-1	• CCSDS Proximity-1
- Antenna	• Quadrifilar Helix	• Patch Antennas (2)	• Quadrifilar Helix	• Quadrifilar Helix
- Forward Link				
- Frequency	• 437.1 MHz	• 437.1 MHz	• 435-450 MHz	• 435-450 MHz
- Data Rate	• 8, 32 kbps	• 8 kbps	• 8, 32, 128 kbps	• 8, 32, 128 kbps
- Coding	• Uncoded	• Uncoded	• (7,½) Convolutional	• (7,½) Convolutional
- Return Link				
- Frequency	• 401.585625 MHz	• 401.585625 MHz	• 390-405 MHz	• 390-405 MHz
- Data Rate	• 8, 32, 128, 256 kbps	• 2, 4., …, 128 kbps	• 1, 2, 4, …, 2048 kbps	• 1, 2, 4, …, 2048 kbps
- Coding	• (7,½) Convolutional	• (7,½) Convolutional	• (7,½) Convolutional	• (7,½) Convolutional, LDPC
- Other	• 1 bit-per-sample open loop recording	• 1 bit-per-sample open loop recording	• 8-bit I/8-bit Q open loop recording • Suppressed Carrier Modulation • Adaptive Data Rates	• 8-bit I/8-bit Q open loop recording • Suppressed Carrier Modulation • Adaptive Data Rates

TGO & EDM Relay Systems

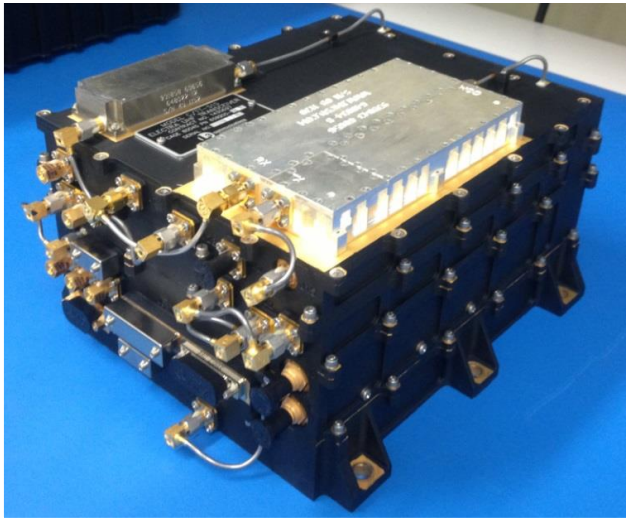
- TGO
  - NASA-provided, flight-redundant Electra UHF transceivers
    - Specs identical to MAVEN Electra
  - Block-redundant UHF quadrifilar helix antennas
    - 6 dBic gain
    - 3 dB beamwidth ±40 deg
- EDM
  - QinetiQ UHF tranceiver
    - Fixed frequency
      - 437.1 MHz forward link
      - 401.585625 MHz return link
  - 4.8 W transmit power
  - 8, 16, 32, …, 1024 kbps return link data rates w/ optional (7,½) convolutional coding
  - 8, 16, 32, 64 kbps uncoded forward link
  - UHF antenna:
    - Backshell LGA UHF patch during Sep and EDL
    - Lander quadrifilar helix after backshell separation



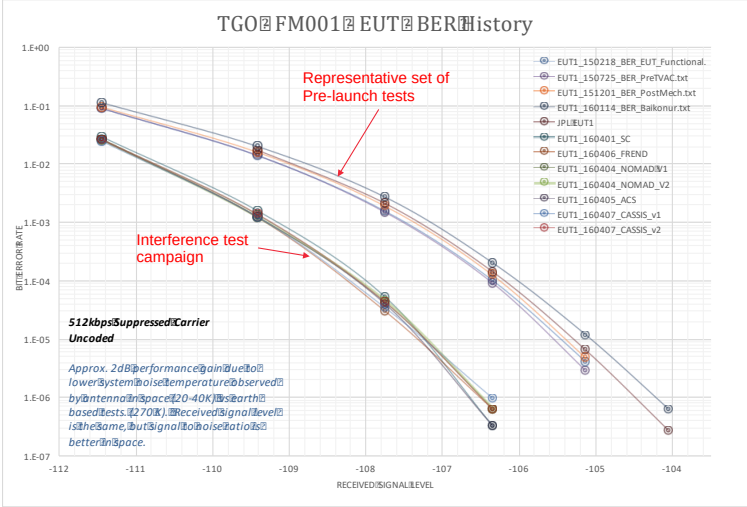


TGO/Electra V&V: Electra Commissioning Status

- Electra commissioning tests performed twice (April 1-2 and June 16)
  - Relay loopback
  - BER loopback
  - Open loop recording
  - *All tests successful for both FMs*
- Interference tests (April 4-7, 18)
  - BER loopback and open-loop tests of both Electra FMs, with TGO science instruments individually or successively powered on
  - *No degradation in Electra performance observed due to any of the TGO science instruments*
- EDM Flight UHF Tests (April 8, June 17)
  - Electra recorded EDM UHF signal transmitted via backshell antenna
  - *Post-processing verified EDM signal detection and recovered EDM telemetry stream*
- Additional EDM Flight UHF Tests
  - Aug 11: Flight-like Electra EDL sequence (w/o EDM txmt)
  - Sep 21: Flight-like Electra SEP and EDL sequences (w/ EDM txmt)
  - *All Electra open-loop recordings post-processed and validated; Sep 21 test recovered EDM telemetry streams*

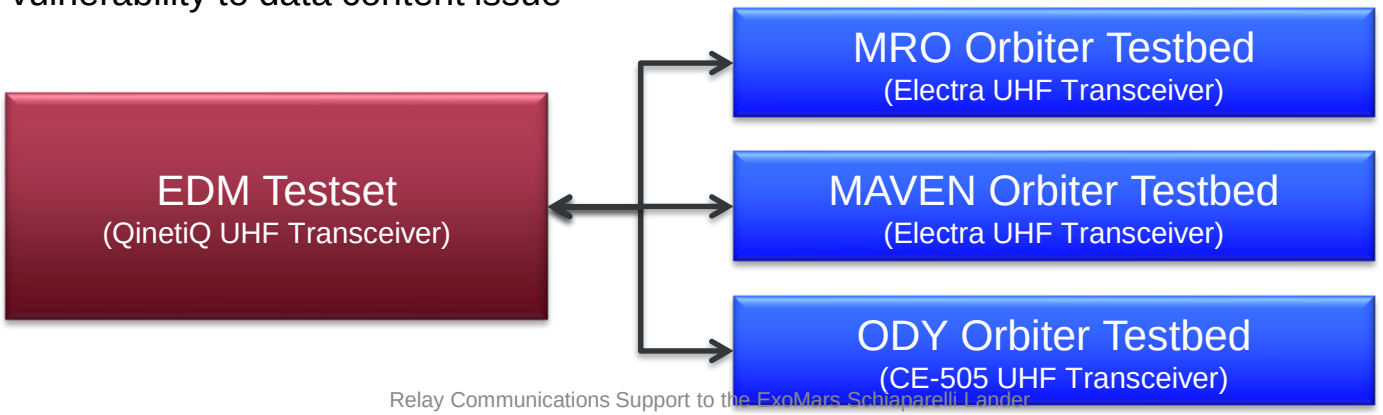


TGO Electra UHF Transceiver



EDM-Mars Relay Network Interoperability V&V Testing

- An extensive series of interoperability tests was conducted 20 July - 12 Aug 2015 at LMSS (Littleton, CO)
  - EDM testset with QinetiQ UHF transceiver and EDM Central Terminal and Power Unit (CTPU)
  - MRO, ODY, and MAVEN Orbiter Testbeds
- Tested all planned relay modes for each orbiter
  - Verified all planned MRO and MAVEN relay functionality
  - Identified two interoperability issues on EDM-ODY link that preclude use of Prox-1 protocol; only unreliable “Raw Data” return link mode is possible with ODY
  - Resulting EDM relay plan incorporates test results into planned use of ODY contacts
- Additional interoperability issue discovered in Aug 2016 MRO/MAVEN testing
  - Highly non-random data patterns (not expected in flight) can lead to link degradation for Adaptive Data Rate/Suppressed Carrier link mode
    - Vulnerability exists due to lack of a scrambler in ESA’s transceiver implementation
  - To mitigate risk, a portion of the MRO/MAVEN passes are now configured in Fixed-Rate/Residual Carrier mode, with somewhat reduced relay performance but no vulnerability to data content issue



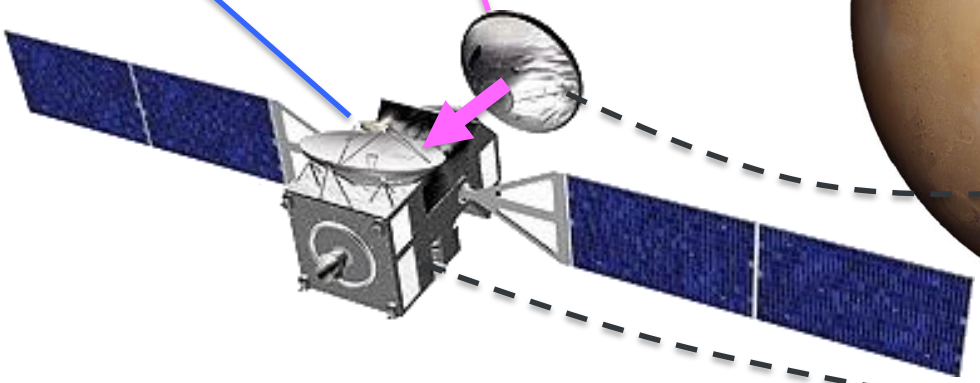
EDM Separation (Oct 16th)

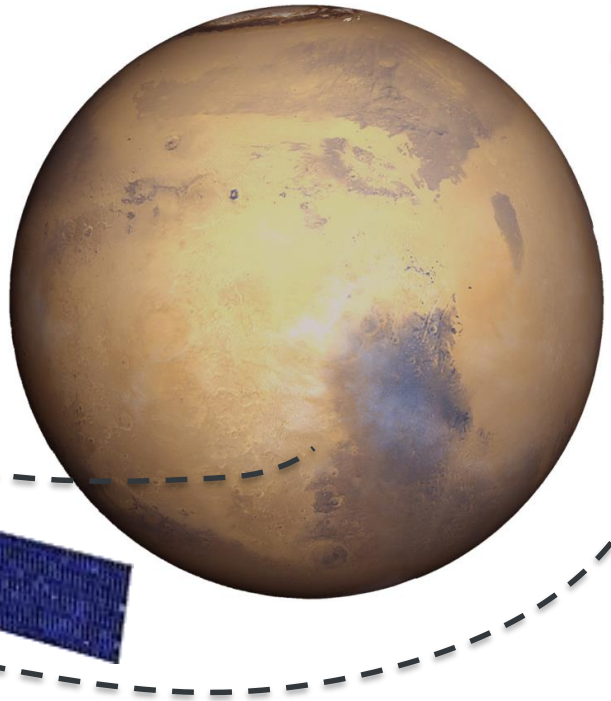
GMRT

ESTRACK

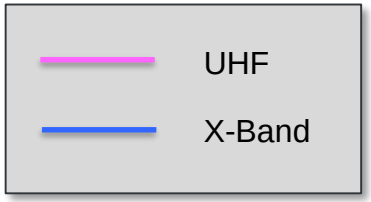
Best-efforts real-time EDM UHF carrier detection @ GMRT

Post-event X-band playback to ESTRACK; post-processing to recover EDM telemetry (~12 hrs)

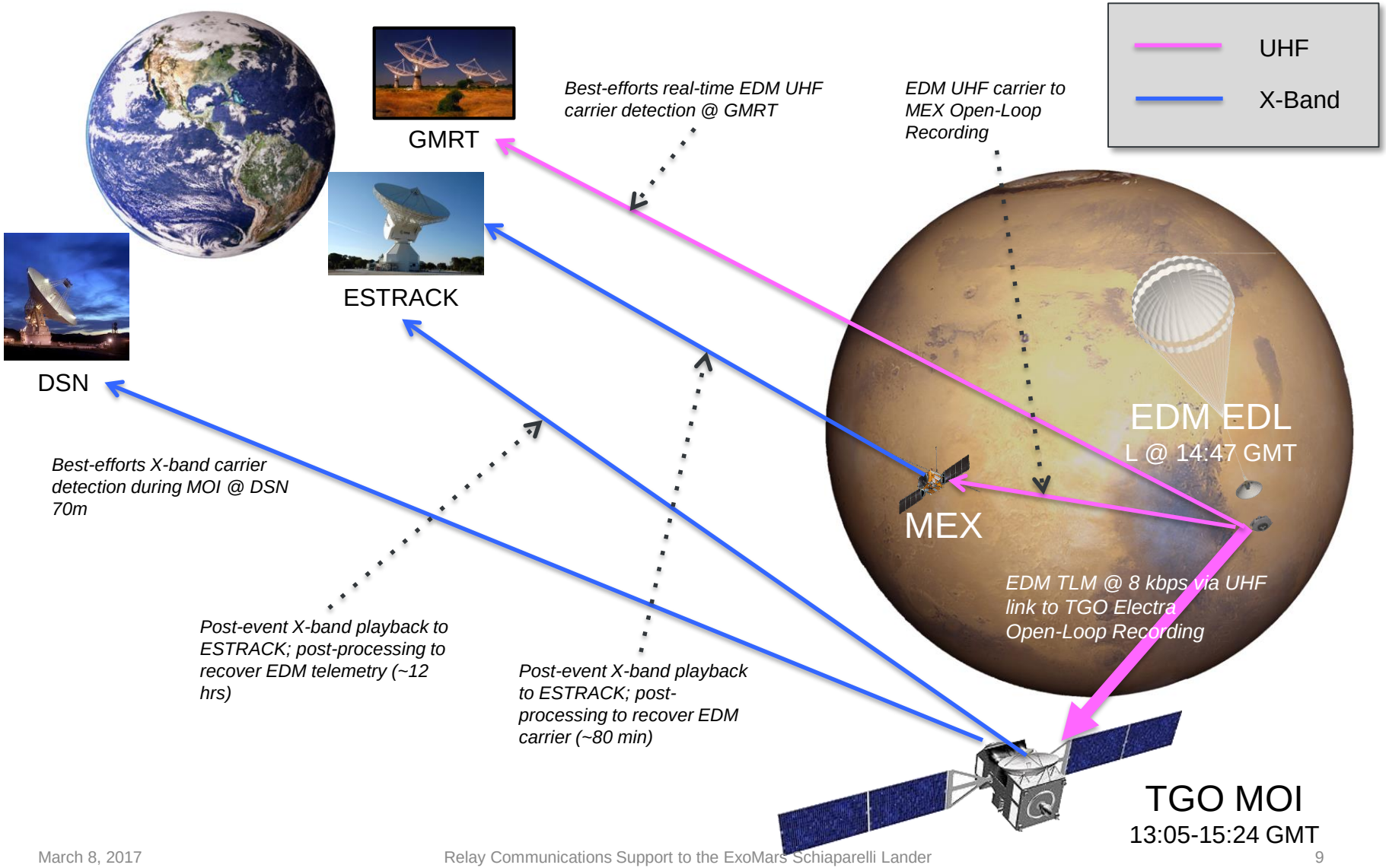




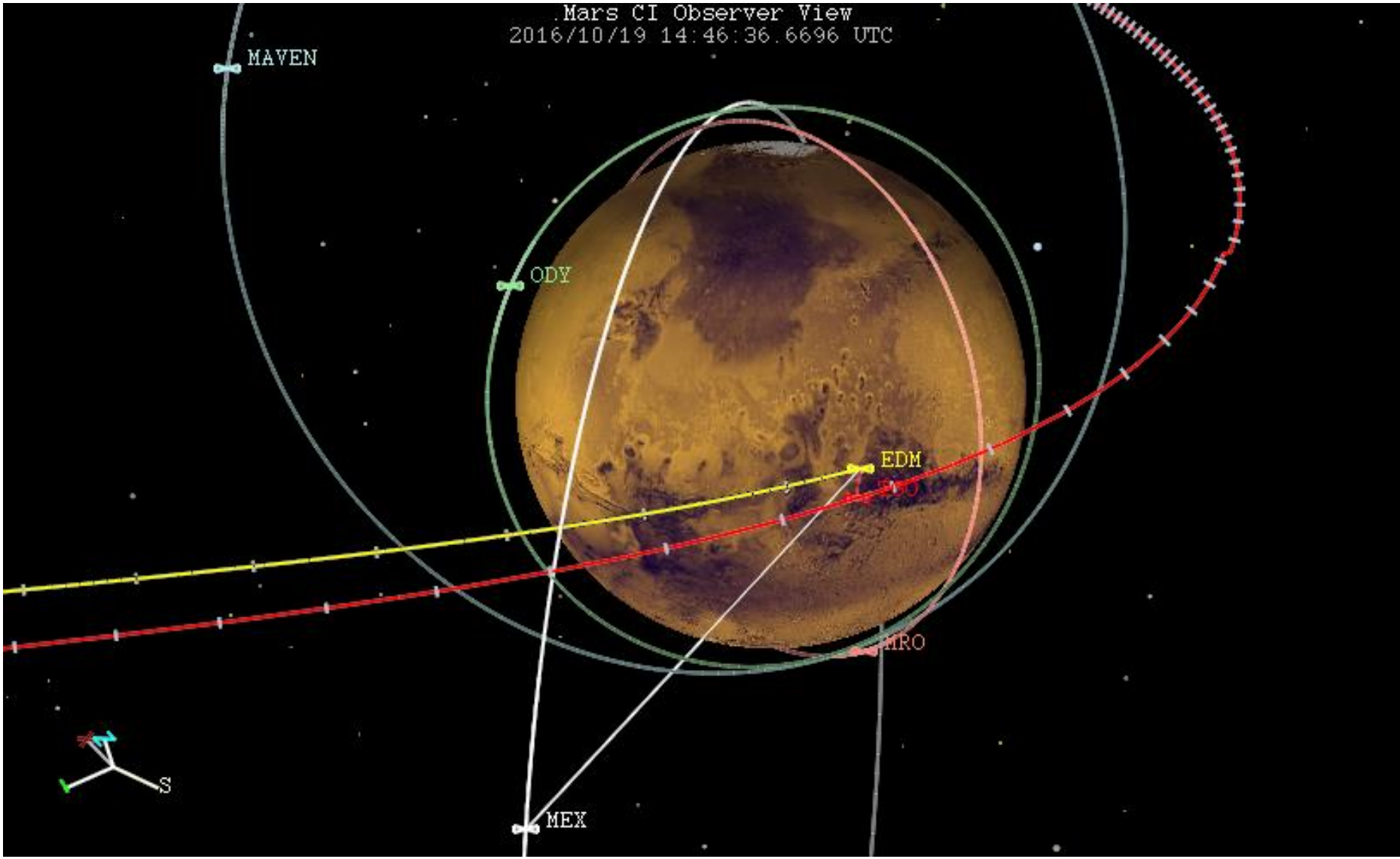
EDM TLM @ 8 kbps via UHF link to TGO Electra



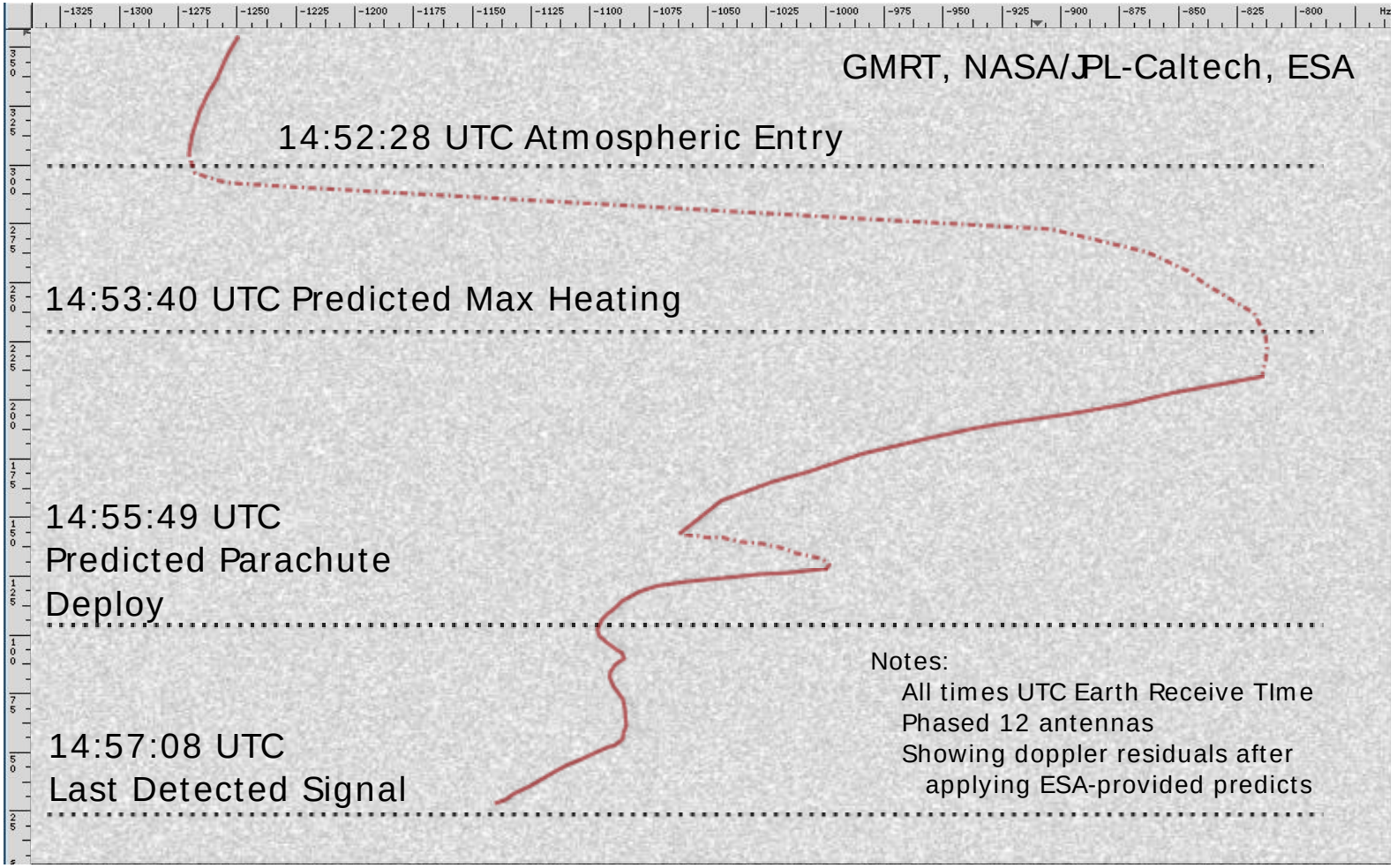
TGO MOI and EDM EDL (Oct 19th)



TGO/EDM Arrival Geometry



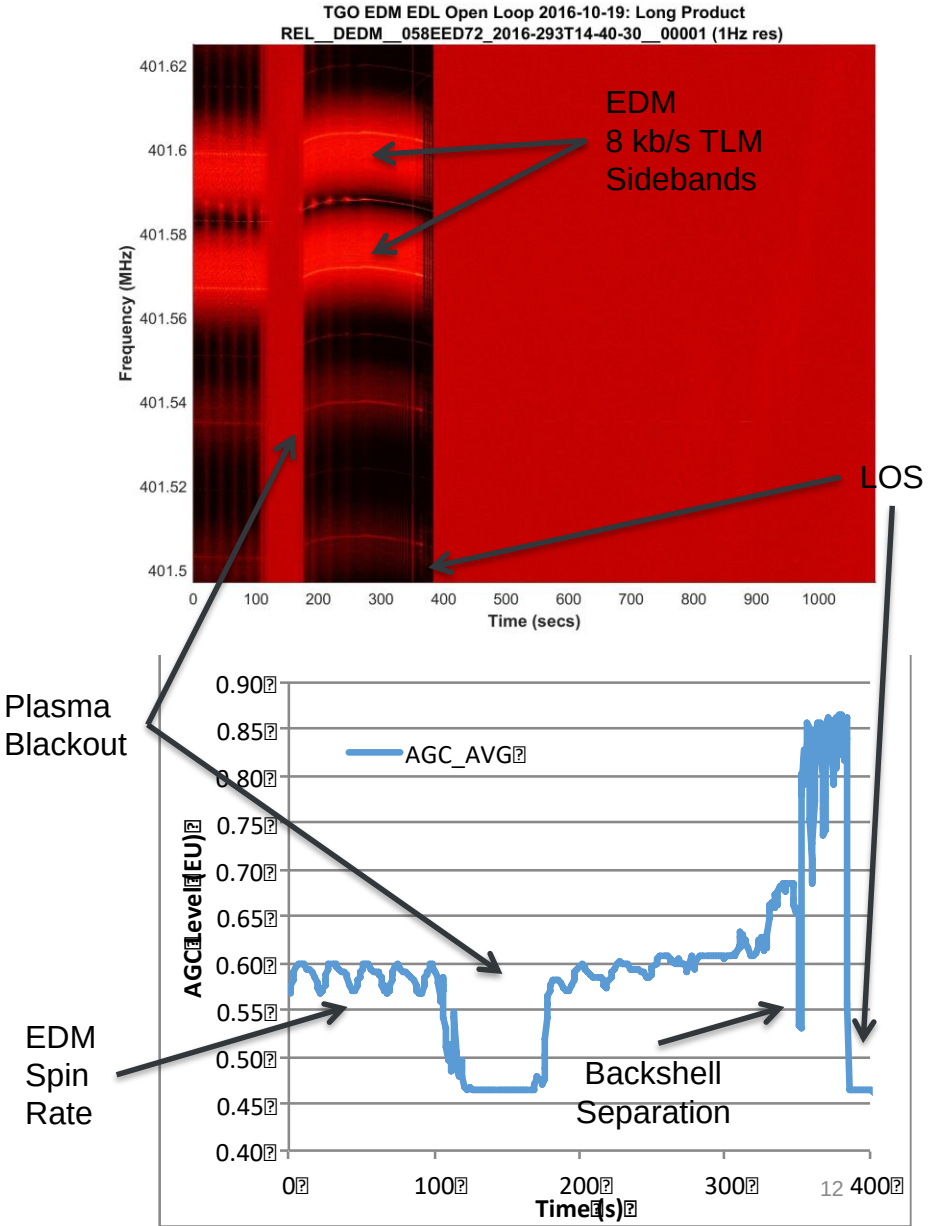
GMRT Observed Residual Carrier Frequency



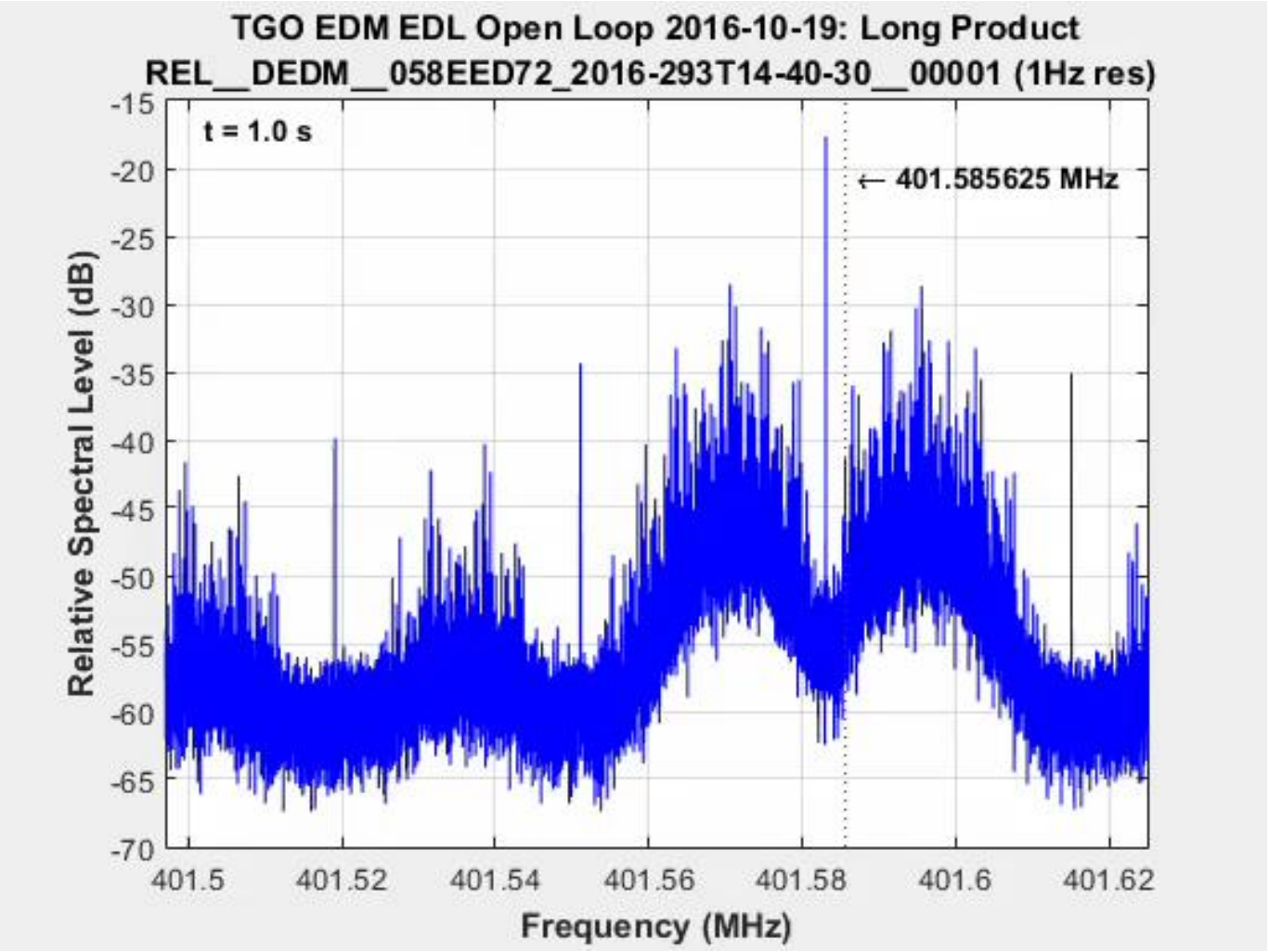
TGO Electra Post-Processing

- ESA and NASA/JPL performed independent post-processing of the TGO/Electra open-loop recording to recover EDM spectrogram and telemetry
  - 7.6 Mb of EDM telemetry recovered in validated Prox-1 frames
  - ESA/JPL working to recover any additional partial frame products
  - Dataset is key to validating successful elements of EDL and supporting ESA diagnosis of landing anomaly

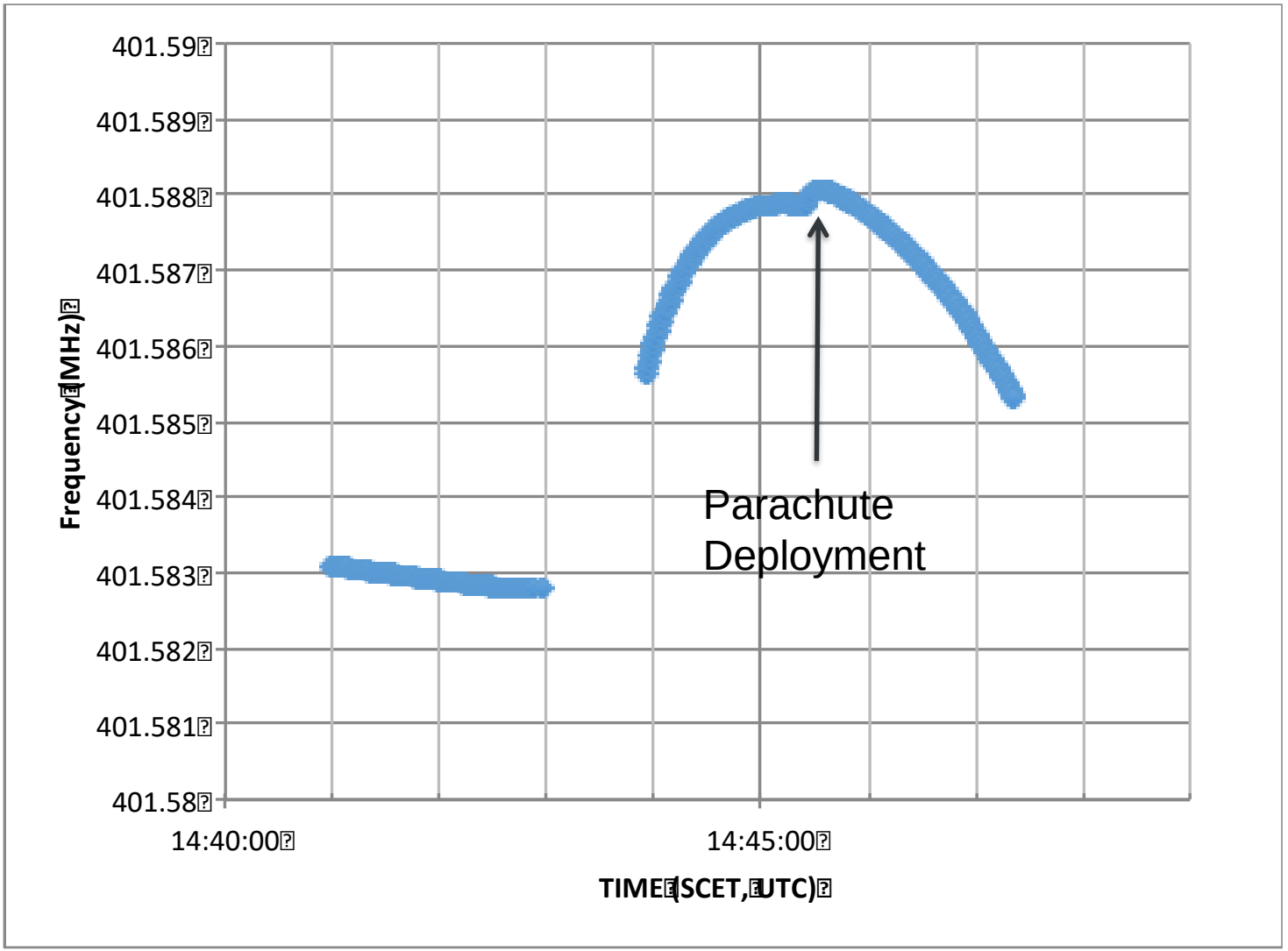
	File 1 (Pre-Entry)	File 2 (EDL)
Start (UTC)	293T14:22:44	293T14:40:59
End (UTC)	293T14:37:09	293T14:59:09
Duration	865 sec	1090 sec
Recovered Prox-1 Frames	629	260
CRC Errors	27	13



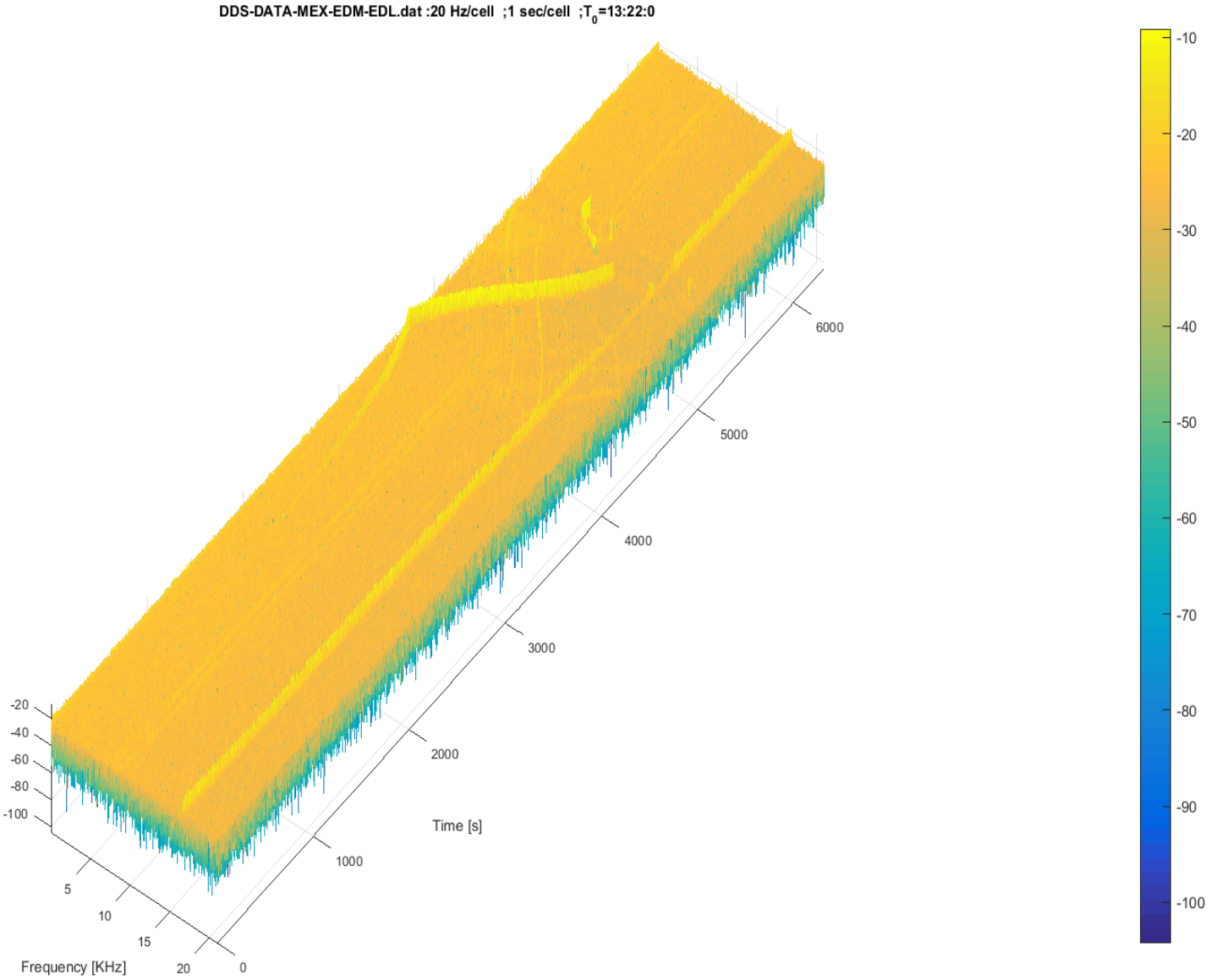
TGO Electra EDM EDL Observed Spectrum



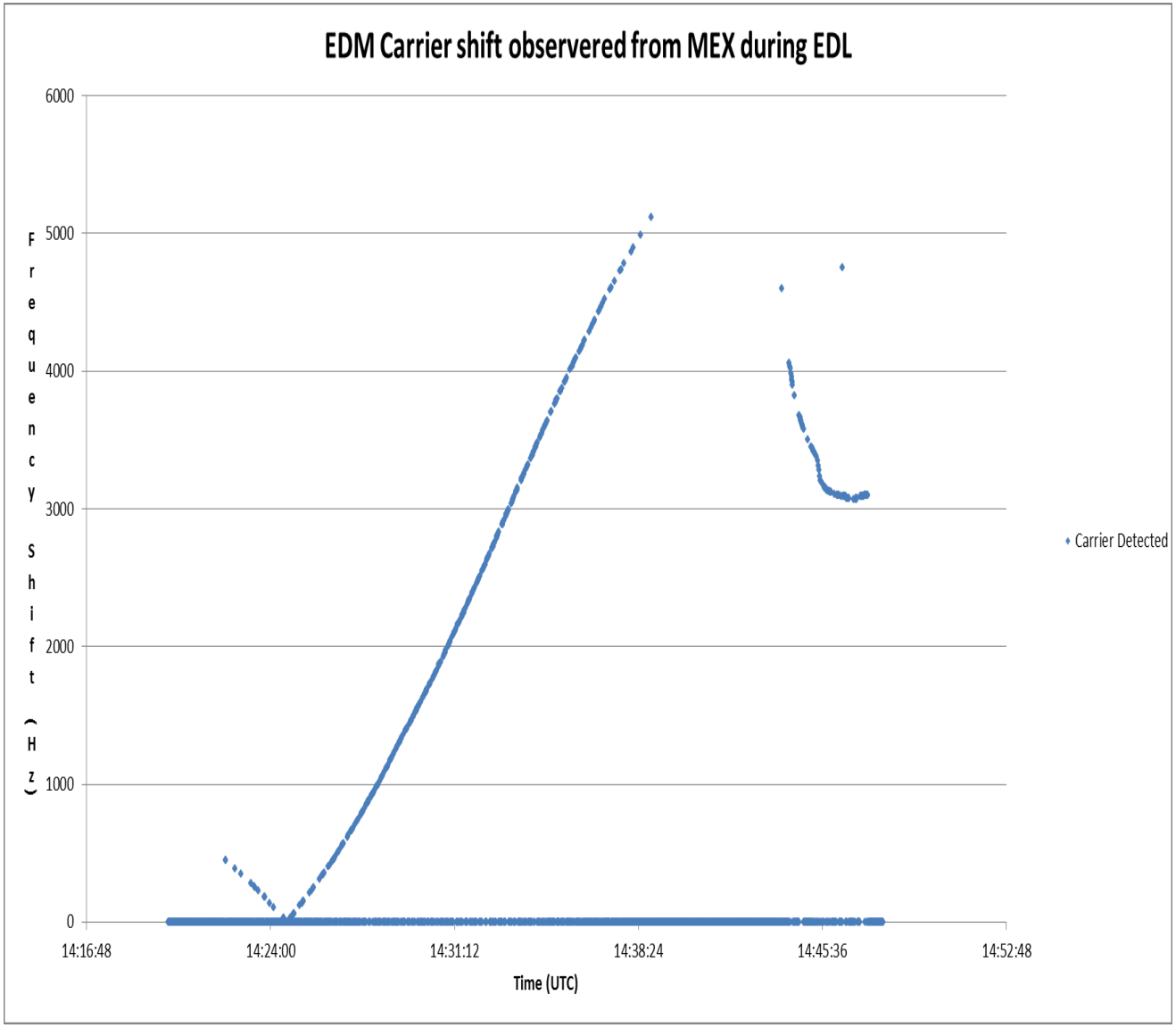
TGO/Electra Recovered Carrier Frequency



MEX Canister Mode Spectrogram



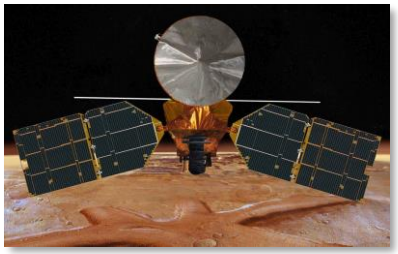
EDM Carrier Freq From MEX Recording



EDM Surface Relay Support

- After MOI, TGO entered a highly elliptical 4-sol orbit, and was not available to provide relay support to the EDM
- Relay service plan was to spread relay service across all available relay assets and use multiple proximity link modes to reduce risk
  - 46 scheduled relay passes over 14 sols

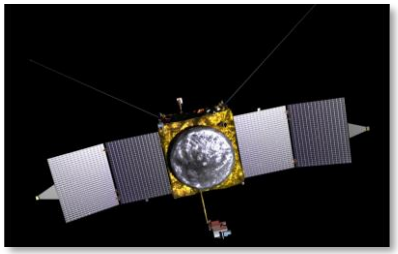
MRO



18 Passes

- *3 passes in Adaptive Data Rate, Prox-1 Mode*
- *12 passes in Fixed-Rate, Prox-1 Mode*
- *3 pass in Open-Loop Mode (8k EDM txmt over simplex return link; no Prox-1 protocol; no hail required)*

MAVEN



6 Passes

- *1 pass in Fixed-Rate, Prox-1 Mode*
- *5 Passes in Adaptive Data Rate, Prox-1 Mode*

Odyssey

8 Passes

- *All passes in Fixed-Rate, Raw Data Mode (EDM txmt over simplex return link; no Prox-1 protocol; no hail required)*

Mars Express

14 Passes

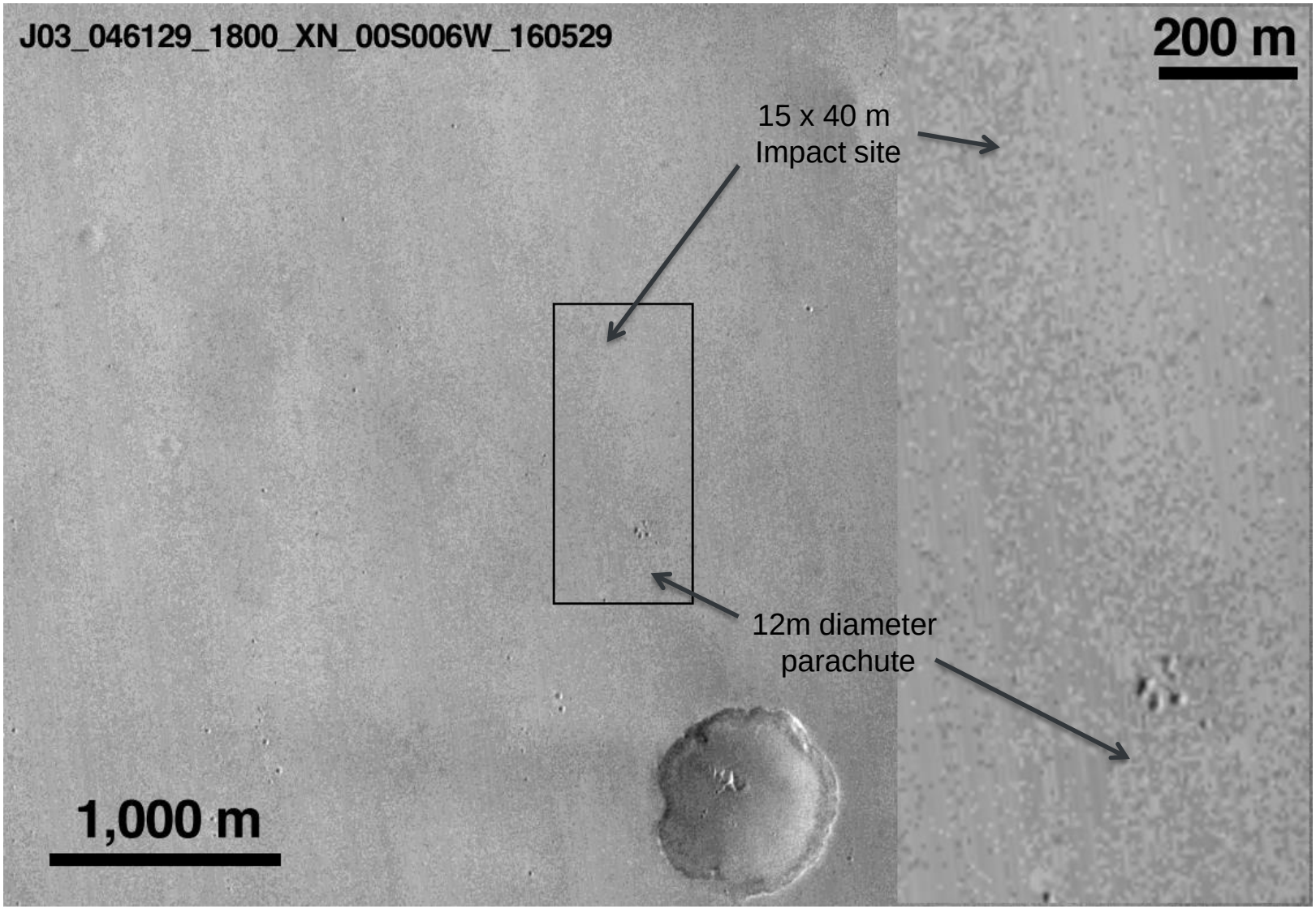
- *5 passes in Fixed-Rate, Prox-1 Mode*
- *9 passes in Open-Loop (Carrier Detect) Mode; these passes are all scheduled with GMRT in view for simultaneous DTE carrier detection as needed*

Post-Landing Relay Passes

- Over the first ~30 hrs on the surface, relay contact with EDM was attempted by all four available relay orbiters, with no response detected
  - **MRO**_EDM_2016_293_03 (Sol 0, ~3 PM LMST)
  - **MRO**_EDM_2016_294_01 (Sol 1, ~3 AM LMST)
  - **MEX**_EDM_2016_294_02 (Sol 1, ~9 AM LMST)
    - GMRT also listened in during this pass and reported no signal detection
  - **MRO**_EDM_2016_294_02 (Sol 1, ~ 3 PM)
    - LMST (MRO also imaged the center of the *a priori* Schiaparelli landing ellipse during this overflight with HiRISE and CTX; CTX image showed apparent EDM crash site)
  - **MVN**_EDM_2016_294_03 (Sol 1, ~6 PM LMST)
  - **ODY**_EDM_2016_294_03(Sol 1, ~7 PM LMST)
- On Oct 21, ESA released NASA from all further EDM relay support

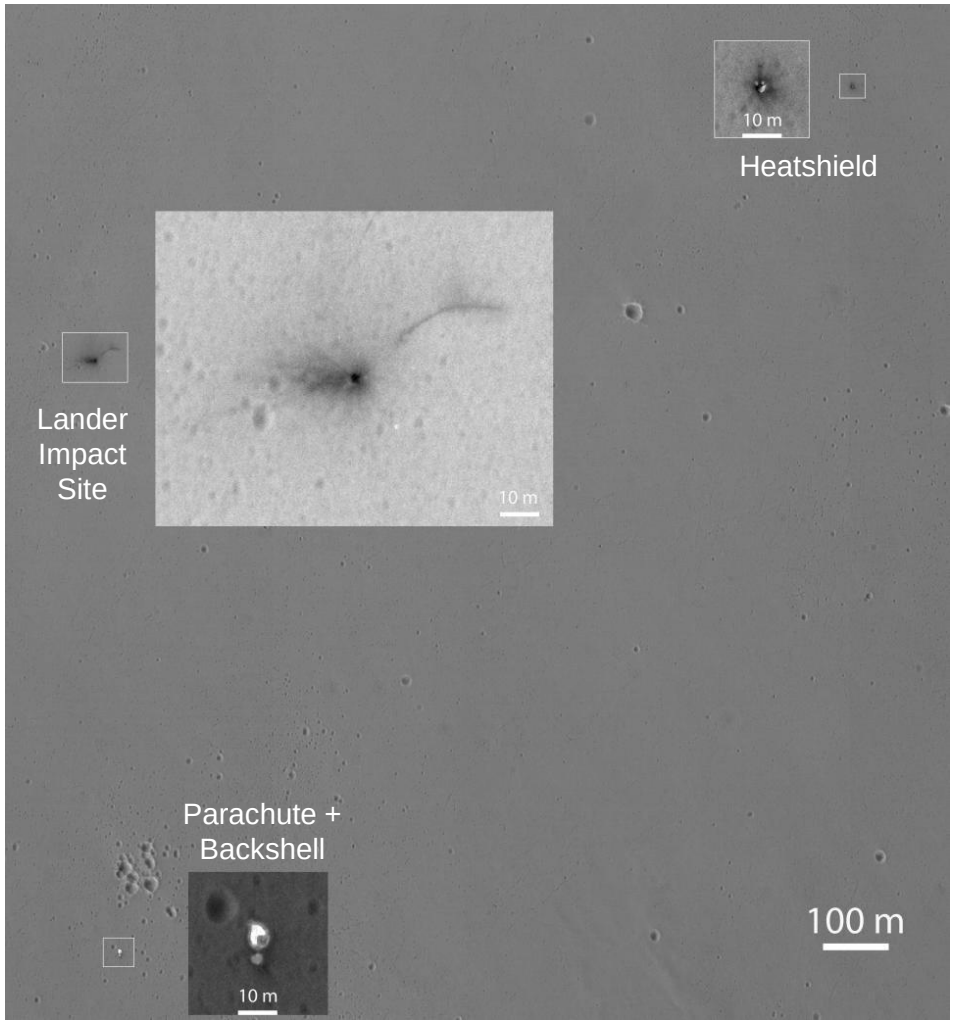
MRO Post-Landing Imaging (1/2)

Comparison of 29-Oct-2016 and 29-May-2016 CTX images

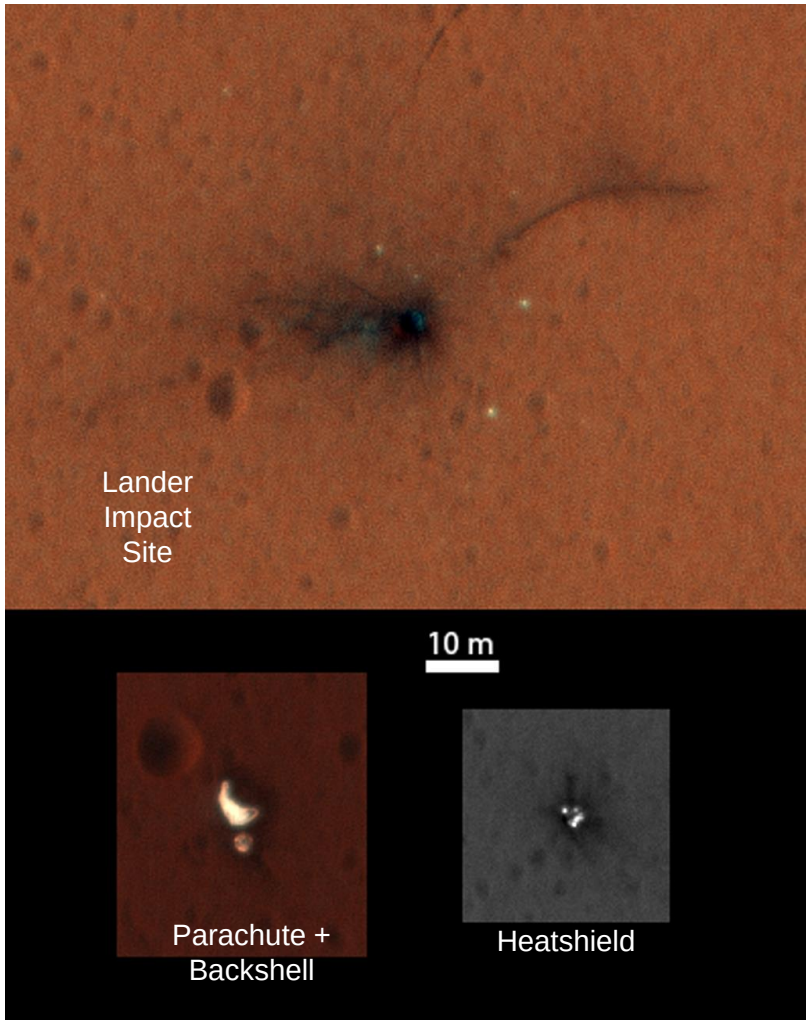


MRO Post-Landing Imaging (2/2)

Oct 25, 2016 MRO HiRISE Image

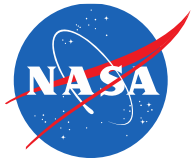


Nov 1, 2016 MRO HiRISE Image



Summary

- Successful TGO MOI marks the arrival of the next Mars science/relay orbiter
  - Successful post-MOI maneuvers have put TGO into a 1-sol, 74-deg inclination orbit
  - ~1-yr aerobraking set to begin on 15 Mar, 2017, targeting final 400-km science/relay orbit
- Robust critical event coverage during Schiaparelli Lander EDL by TGO/Electra, MEX, and GRMT, have provided comprehensive data set supporting full diagnosis of the EDL anomaly
- Preparations for surface relay support provide important lessons-learned for future interagency relay cross-support
  - TGO relay support to NASA landers/rovers
  - NASA orbiter relay support to ExoMars 2020 RSP mission



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